

Range-Depth Tracking of Sounds from a Single-Point Deployment by Exploiting the Deep-Water Sound Speed Minimum

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LONG-TERM GOALS

The long-term goal of this work is to develop techniques for tracking marine mammal sounds in range and depth from a single mooring or platform (e.g. glider), by exploiting the propagation effects of the deep-water sound speed channel. Most listening platforms currently use a single hydrophone to detect events, making no effort at localization. For beaked whales (which have a limited detection range of about 5-7 km), detection may be sufficient to determine whether an animal is close to potential naval operations, but for most species, one needs to assume a typical source level (or source level distribution) to translate a detection's received level into a distance, a risky assumption that generates large uncertainties in position, which in turn degrades attempts at acoustic density estimation and makes mitigation decisions problematic.

The range of a marine mammal sound from a compact platform can also be obtained by detecting the same event across multiple platforms; however, for logistic reasons it is highly desirable to investigate avenues for permitting relatively accurate localization from a single platform.

OBJECTIVES

The primary objective of the work is to estimate the range and depth of cetacean calls using short-aperture vertical arrays, by measuring the vertical arrival angles of various refracted and bottom-reflected ray paths, and the relative arrival times between them. Single-hydrophone methods are also being examined, with a particular focus on empirical relationships between the bandwidth and temporal dispersion of received signals with measured range. Two broad classes of calls are to be examined: deep-diving odontocetes such as sperm and potentially beaked whales, and shallow-diving mysticetes, with a focus on humpback whales.

The short-aperture range estimates are to be verified by comparison with satellite-tag positions (for sperm whales) or by comparison with ranges obtained via large-aperture vertical array techniques (for humpback whales).

APPROACH

The experimental approach used by this project uses data collected by moored vertical arrays in deep water, to simulate data that would be collected by autonomous platforms. At present three experimental deployments are being used. The first is a 2010 deployment of a two-element 10-m aperture vertical array on longline fishing gear off Sitka, AK. The three-day deployment occurred in the midst of several depredating sperm whales, three of which had been tagged by satellite tags just before the deployment. Location fixes from the satellite tags are used to evaluate range estimates derived from angular measurements of the vertical array, as well as range estimates derived from heuristic expressions for pulse dispersion in the sound-speed minimum channel. The basic analytic approaches used here have previously been published by Mathias *et al* 2013.

A second deployment scheduled during this project is that of a large-aperture vertical array in the same region off Sitka, AK. The sparse array actually consists of several subarrays, including two eight-element arrays (21 m aperture) deployed at 90 and 275 m depths (the latter being the sound speed minimum), and three two-element arrays of 10 m aperture deployed at 238, 640, and 823 m depth. The motivation behind these multiple deployments was that multiple techniques can be used to estimate humpback whale call position, and thus cross-validate methods that use a relatively short-aperture array.

A third data source was identified after the award was initially issued: a 10 m aperture “mid-frequency noise array” (MFNA) vertical array deployment with 128 elements, deployed at 330 m depth in 4 km depth water off San Diego in Feb. 2014. Figure 1 illustrates the deployment hardware. The four-day data set, sponsored under a separate MURI research thrust, inadvertently collected numerous sperm, humpback, and dolphin calls. The research project also conducted controlled source tows at depths between 100 and 300 m, to allow independent verification of tracking techniques. The high quality of this data set, combined with the permission of the project PIs to use the data (William Hodgkiss and William Kuperman), has made this data set the focus of subsequent analysis.

WORK COMPLETED

This award was issued on June 2014. On 2014 September 23 a large-aperture vertical array deployment was deployed off Sitka at 56.61 N, -135.93 W. The system was recovered in mid-October 2014, but the data quality of most of the elements was poor, because of mechanical noise against the 8-element cables, and insufficient subsurface floatation was used, which led to uncertainty in the depths of the working elements.

Instead of attempting to repeat the deployment, this effort has focused on analyzing both humpback whale and sperm whale data from the MFNA data set discussed above.

The analysis has focused on two topics: (1) How a short-aperture array can be used to track low-frequency baleen whale calls in deep-water environments, and (2) whether “double-difference” techniques developed in seismology and recently applied to fin whales (Wilcock, 2012) could also be applied to sperm whales on vertical array data. The method allows the *relative* positions of acoustic

events (i.e. the trajectory of an animal's path) to be measured precisely, even though the exact absolute position cannot be precisely determined, due to uncertainties in array tilt and the propagation environment. To our knowledge double difference methods have not been previously applied to underwater acoustic array systems.

RESULTS

(1) Humpback whales have been localized in range using the 10 m aperture MFNA vertical array. Figure 2 shows a spectrogram of some example calls, while Figures 3 and 4 show how a humpback whale call yields two arrival paths, with a relative time delay of 73 msec. The strongest path is a purely refracted path, while the path arriving from the direction of the ocean floor (positive angle) actually turns out to be a surface-reflected path. Figure 5 shows how all three pieces of information (two angles and one relative arrival time) can be used to set the range to 53 km, if one uses the prior information that humpback whales call at depths less than 200 m.

(2) Sperm whales have also been localized. Figure 6 shows a spectrogram of both sperm whale sounds and towed source FM sweeps generated from a known location (and thus providing an independent check of the ray tracing measurements). By localizing the whale at two times set fifteen minutes apart, the true range of the whale can be distinguished from other ambiguous locations that arise from uncertainties in array tilt and the propagation environment (Figs. 7 and 8). The true range can be identified as the range that shifts less than 1 km over 15 minutes.

(3) Animal trajectories (relative changes in range and depth between calls) may be measured with a short-aperture array, even if the exact range and depth of the animal at a single time cannot be not well characterized, due to uncertainties in ray arrival angles or the propagation environment. The approach being finalized here uses "double-difference" methods to map the position of multiple acoustic events relative to each other, by noting how relative arrival times between different ray paths evolve over time (the difference in difference of arrival times between two events, or "double differences"). Figure 9 shows an example of how the ray path timing changes for a controlled source being winched from 300 to 100 m depth, while Figure 10 shows similar measurements for a sperm whale.

IMPACT/APPLICATIONS

The results to date suggest that existing mobile platforms with two hydrophones spaced 1 to 2 meters apart may be able to derive sperm whale dive profiles. It remains uncertain whether humpback whale sounds would be localizable with only 2 m apertures.

REFERENCES

- Mathias, D., Thode, A. M., Straley, J., and Andrews, R. D. (2013). "Acoustic tracking of sperm whales in the Gulf of Alaska using a two-element vertical array and tags," *J. Acoust. Soc. Am.* **134**, 2446-2461.
- Wilcock, W. (2012). "Tracking fin whales in the northeast Pacific Ocean with a seafloor seismic network (vol 132, pg 2408, 2012)," *Journal of the Acoustical Society of America* **133**, 2503-2503.

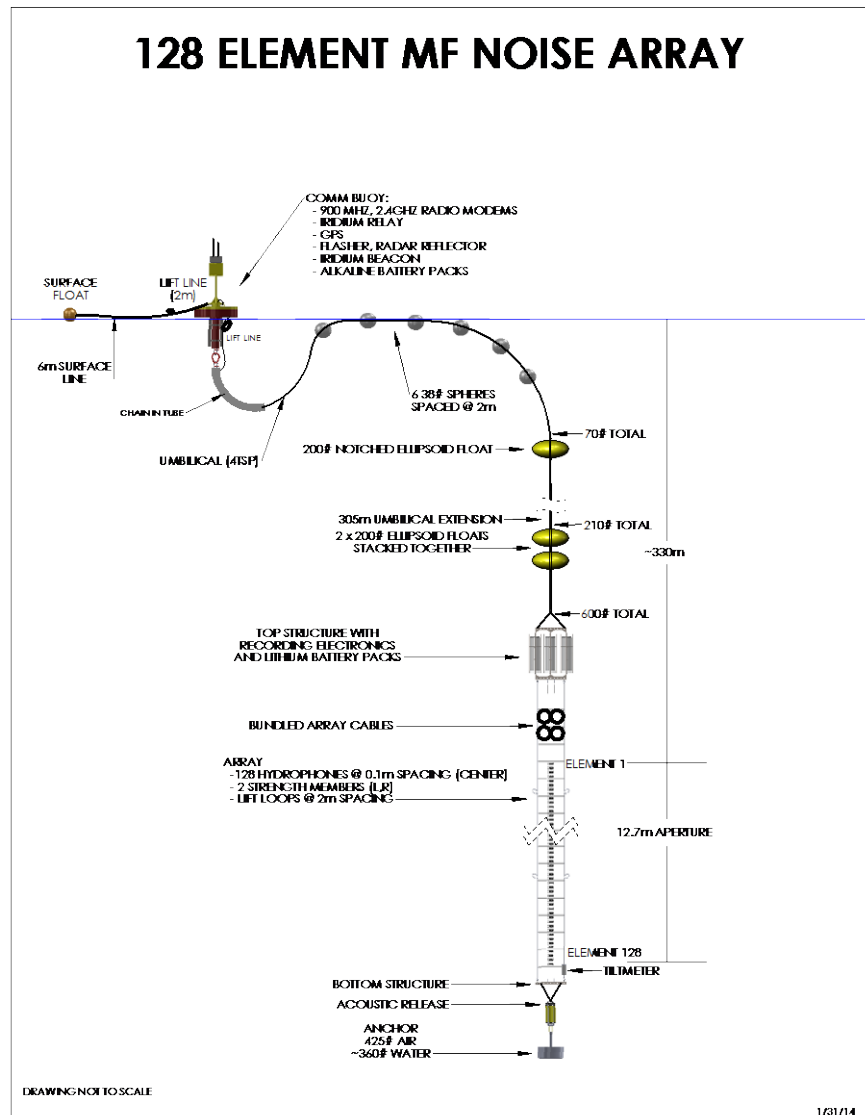


Figure 1: Deployment geometry for MFNA used to study sperm whale and humpback calls.

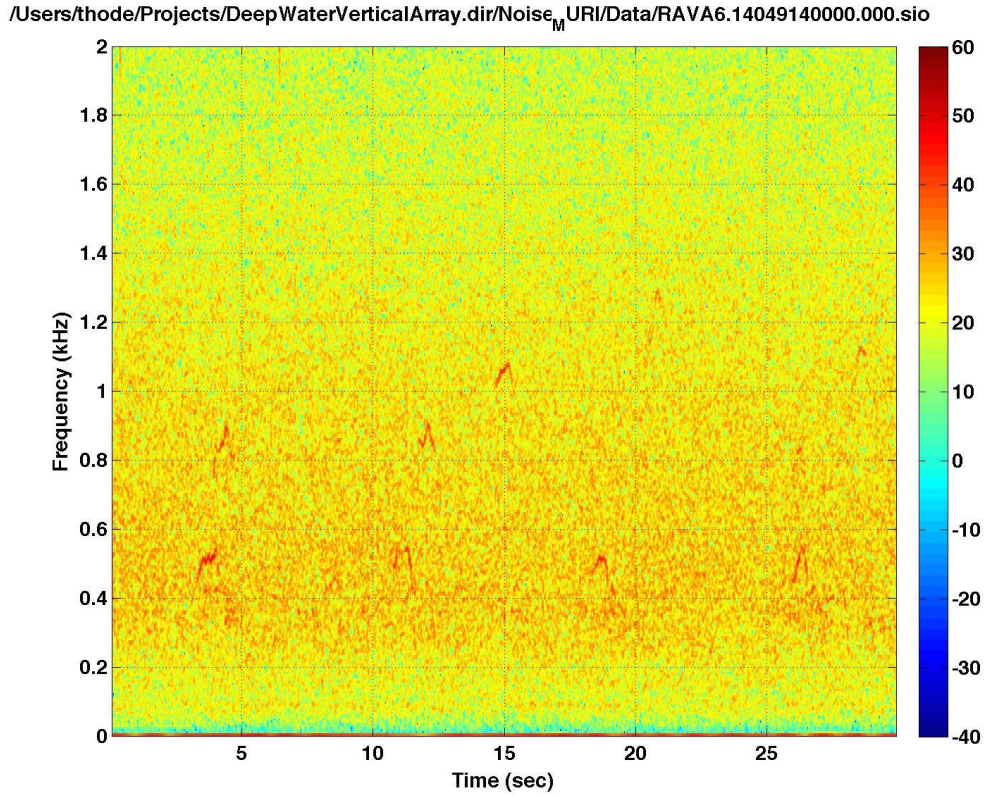


Figure 2: Humpback whale calls detected on MFNA, looking toward the surface (12° above horizontal).

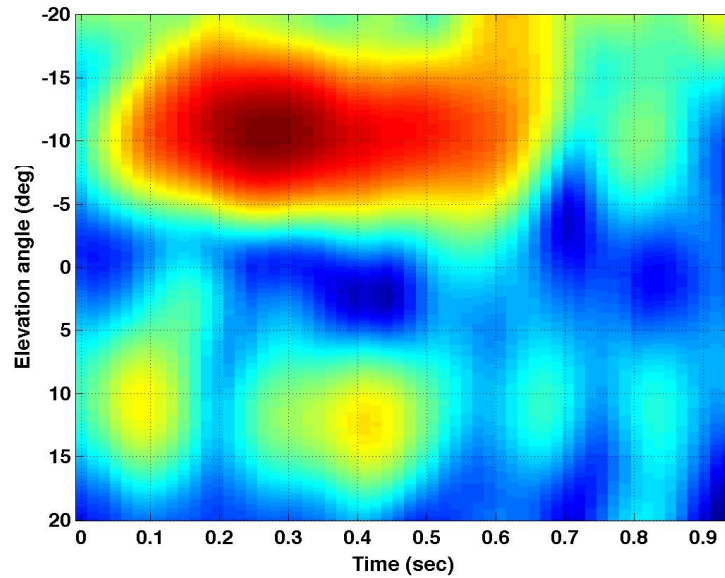


Figure 3: Migration plot of humpback call, showing two ray arrival paths, a purely refracted path (negative elevation angle) and a weaker surface-reflected path (positive angle).

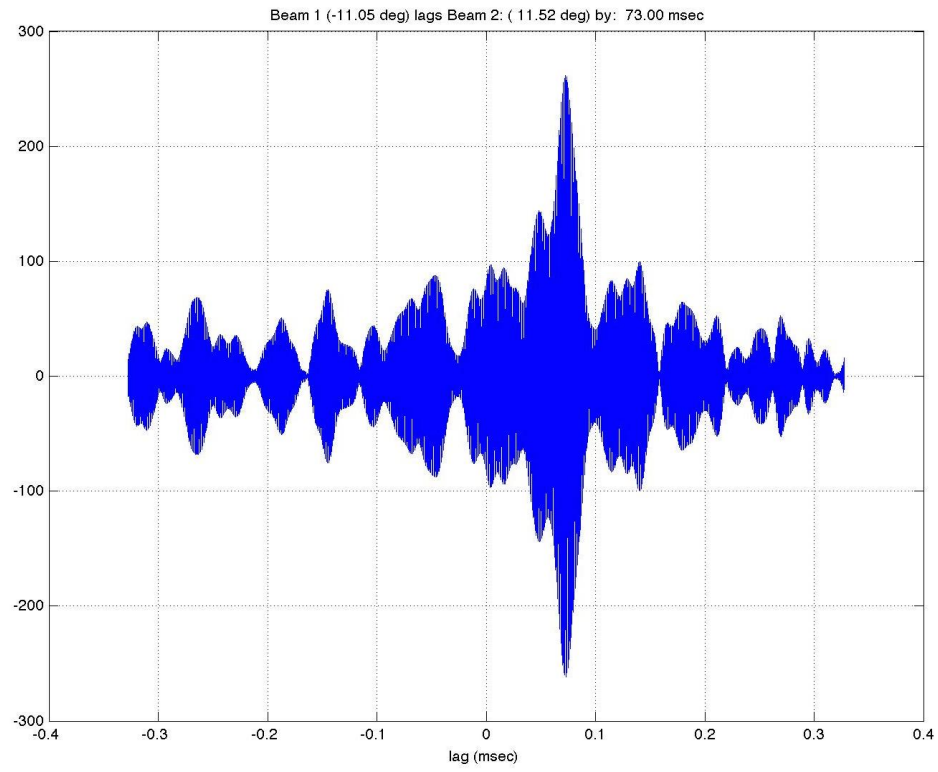


Figure 4: Autocorrelation of two ray paths yields relative arrival times of 73 msec.

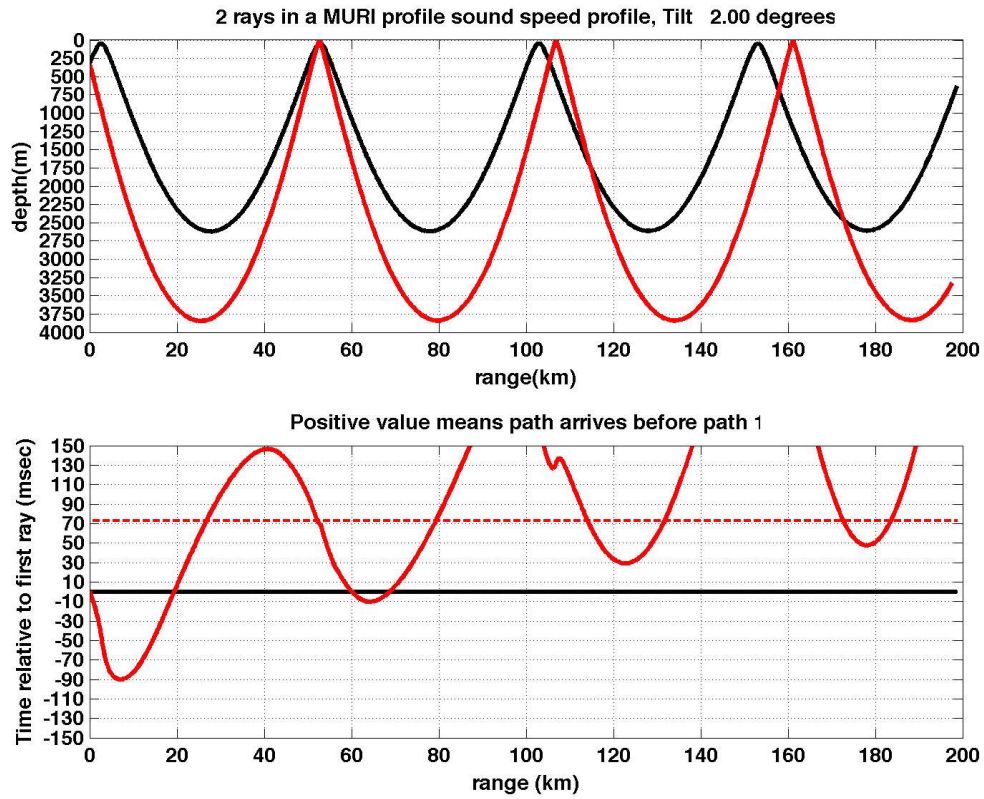


Figure 5: (Top) Ray trace of humpback whale call detected in MFNA data. (Bottom) Relative arrival time of two paths, as compared to measured time delay (horizontal dashed line). Because humpback whales are known to call at depths less than 200 m, the range ambiguity can be eliminated and the call range established at 53 km range.

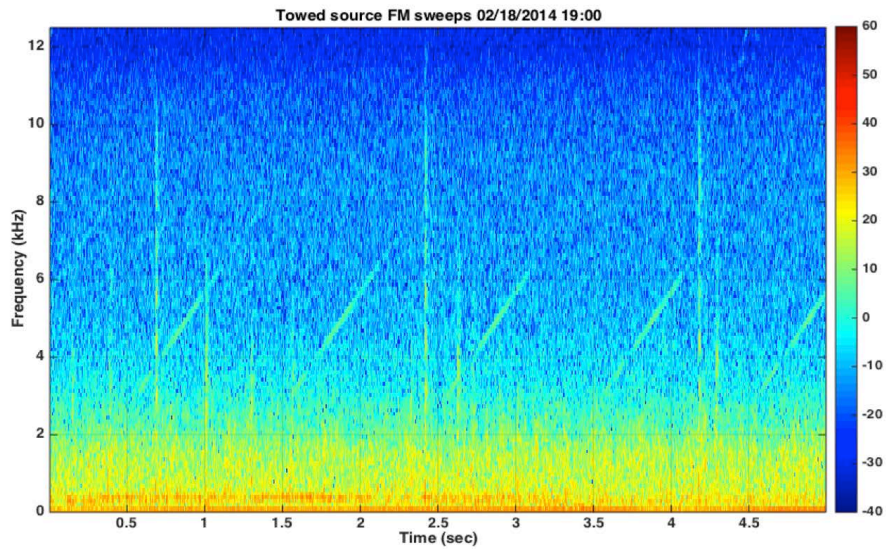


Figure 6: Spectrogram of sperm whale sounds (vertical lines) and towed source FM sweeps (diagonal lines).

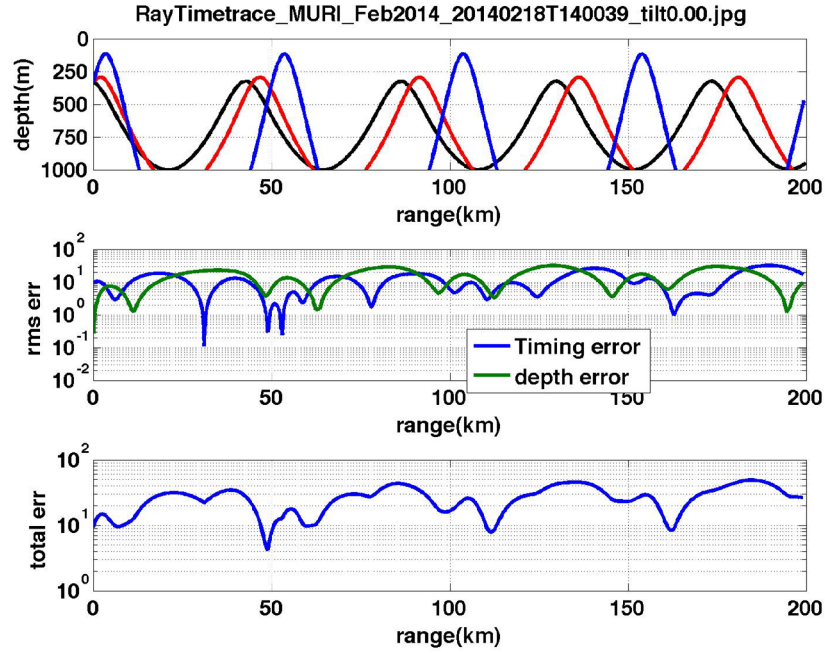


Figure 7: Ray tracing of sperm whale location. Multiple ambiguous solutions exist, as shown by the local minima in the “total err” plot below.

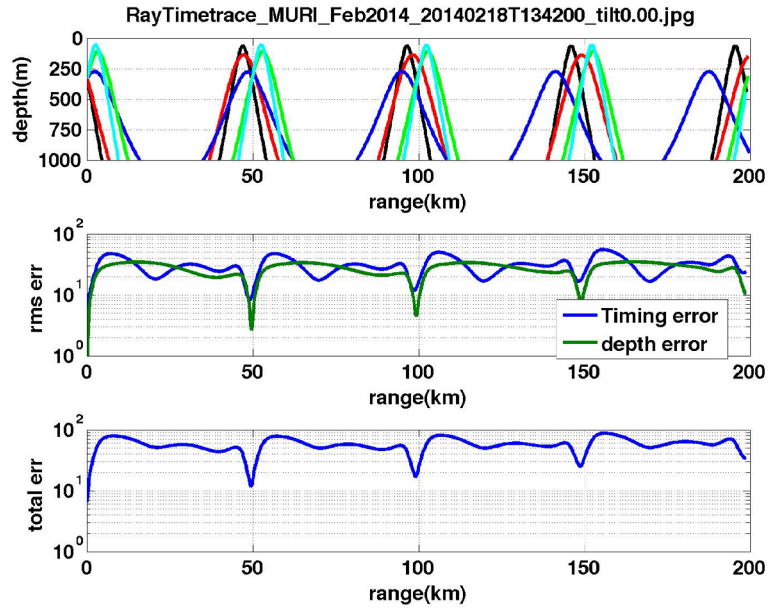


Figure 8: Ray trace of same sperm whale, 18 minutes earlier than Figure 7. Note how false (ambiguous) locations have large shifts in range (e.g. 100 and 150 km range), while the true range at 50 km remains the same.

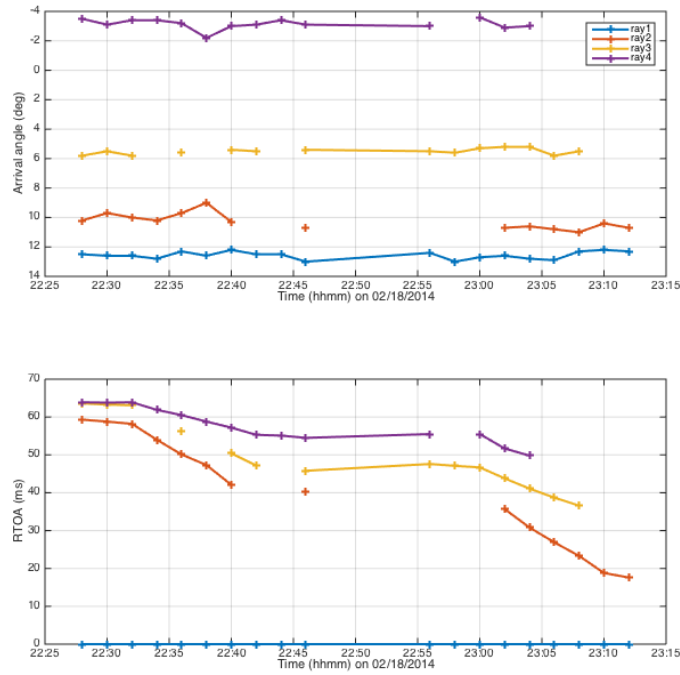


Figure 9: Evolution of ray arrival angles (top) and relative multipath arrival times (bottom) as a controlled source is winched from 300 m to 100 m depth at 49.5 km range.

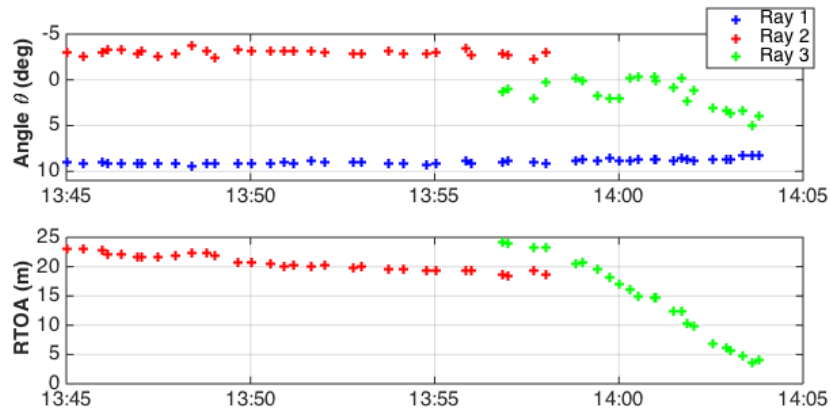


Figure 10: Evolution of ray arrival angles (top) and relative arrival times for a sperm whale click train over 20 minutes.